Liquid tin sputtering experiments in the Ion-surface InterAction eXperiment

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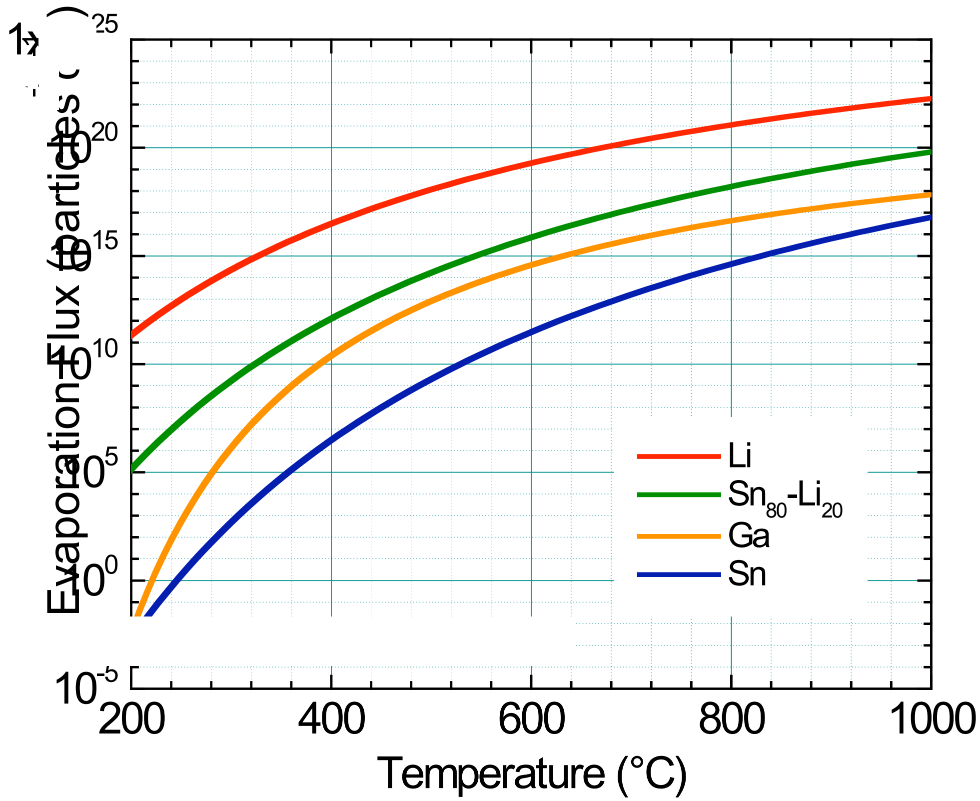
Outline

- Sn sputtering
  - Modeling
  - Experiments
- IIAX modifications/improvements
- Future work
  - Liquid sample sputtering measurements
  - Solid targets for ITER PFC support

Advantage of using liquid <u>Sn</u>

- Sn has an evaporative flux many *orders of magnitude* lower than Li
- Friendly & abundant (cheap!)
- Evaporation curves based on theory by [1] and fits from [2] and [3].

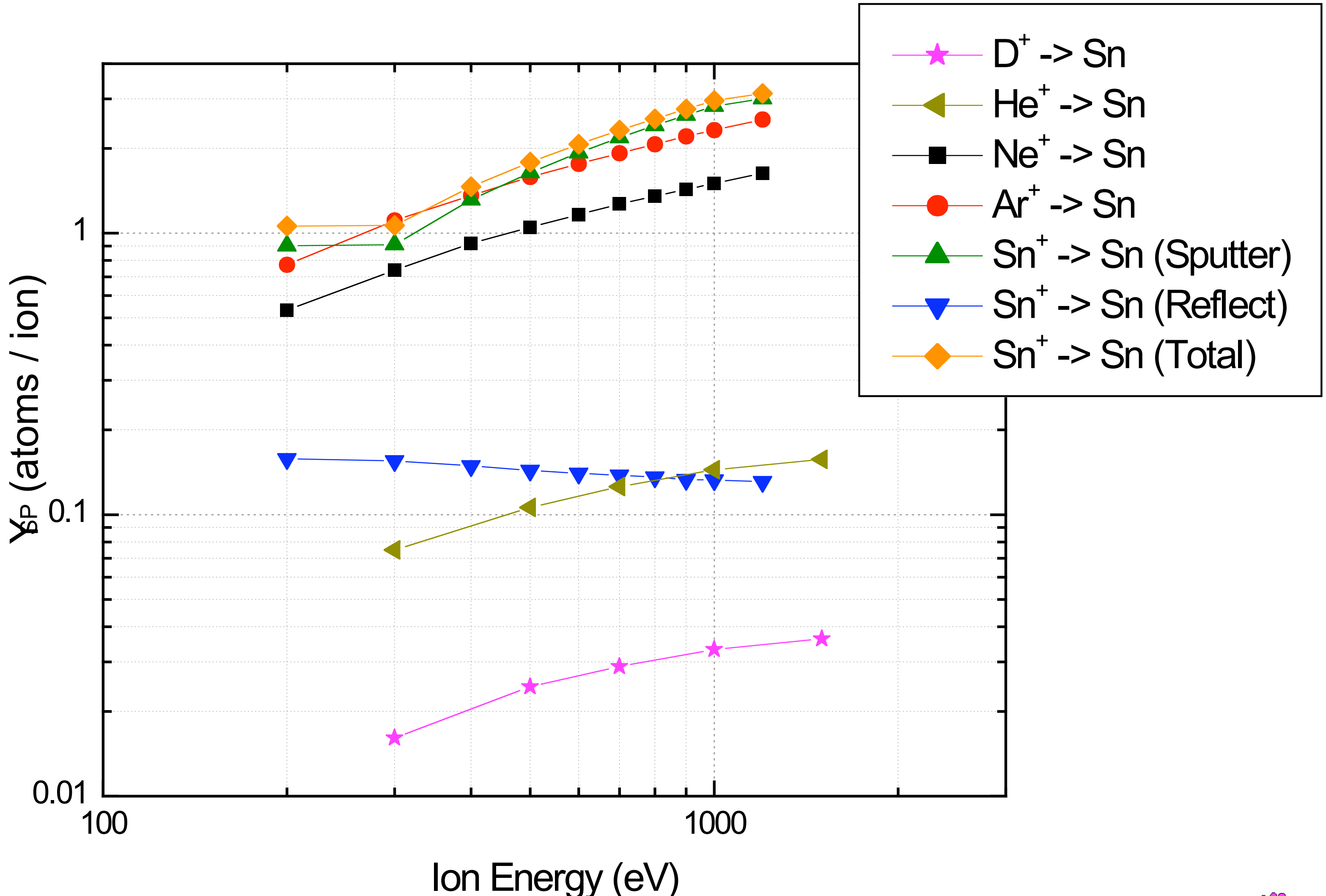


[1] Y. Waseda, S. Ueno, K.T. Jacob, J. Mat. Sci. Let, 8, (1989) 857-861.

[2] M.A. Abdou, A. Ying, N.B. Morley et al., APEX Interim Report Report No. UCLA-ENG-99-206, (1999).

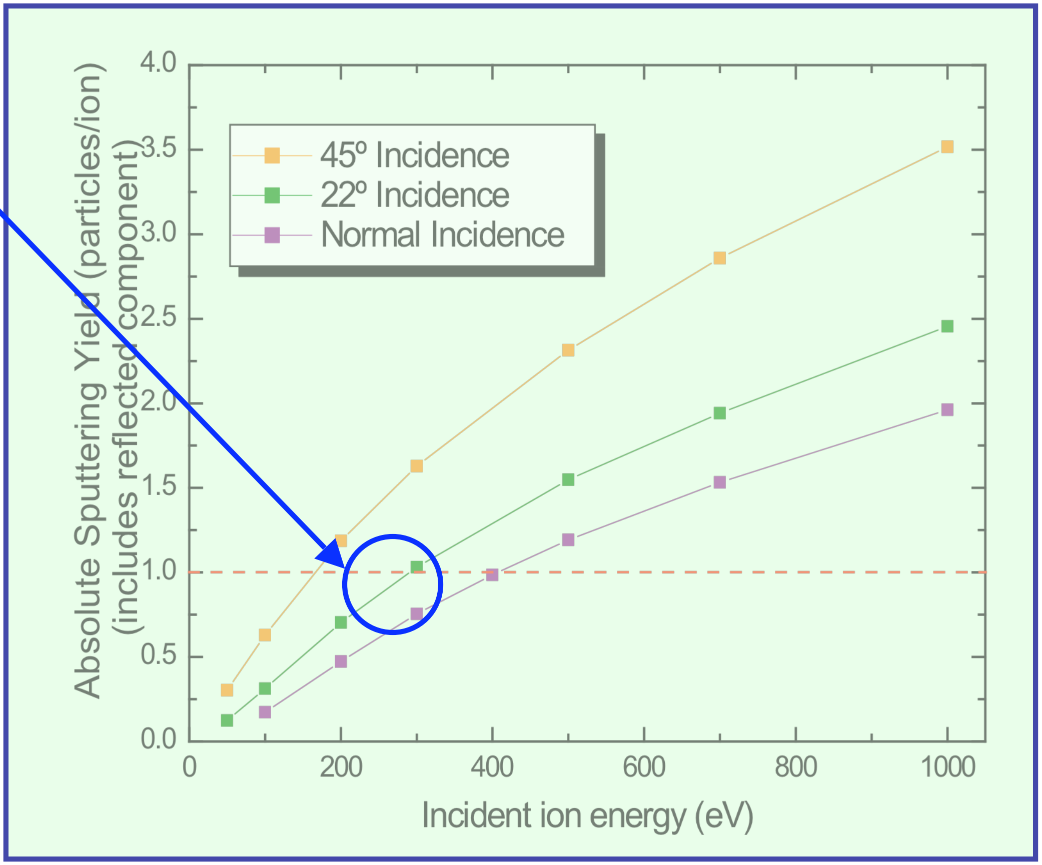
[3] I.A. Sheka, I.S. Chaus, T.T. Mityureva, *The Chemistry of Gallium*, (1966), Elsevier, Amsterdam.

VFTRIM Simulation Results for 45º incidence on solid Sn



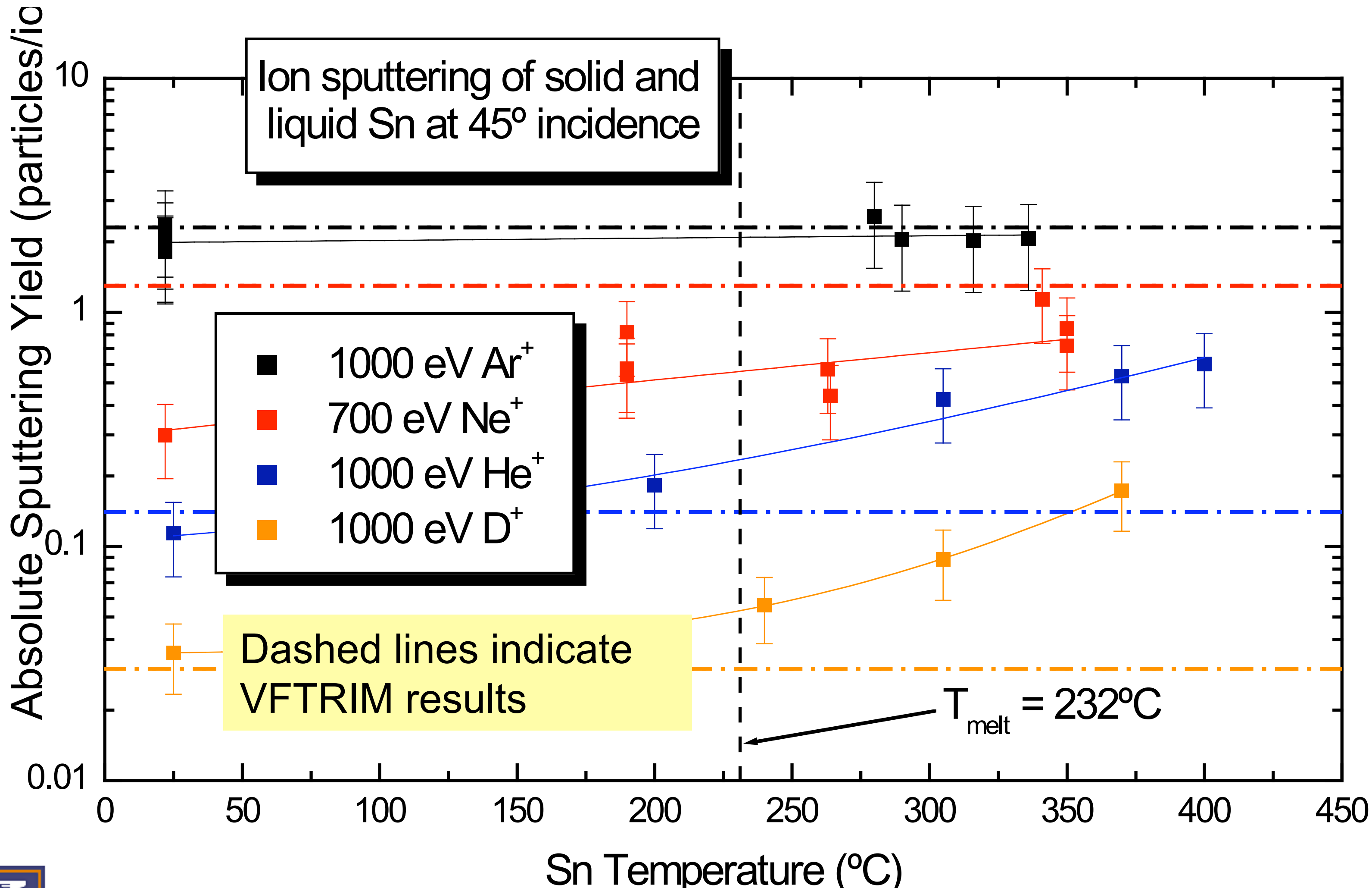
VFTRIM Simulations of Sn self-sputtering

- Sn ions are predicted to have a mean incident angle of 22º and an average energy of 270 eV [1] for an ARIES-AT configuration with a liquid Sn divertor
- Thus, equally important is the reduction from decreasing the angle of incidence
- Normal-incidence runs may be performed in the future to complement the oblique work done here
- D^+ sputtering of liquid lithium was shown to have a drastic (10 to 1000 fold) increase as a result of increasing the temperature



[1] Brooks, J.N. Fus. Eng. Des. **60** (2002) 515-526.

Sn sputtering results from 4 species



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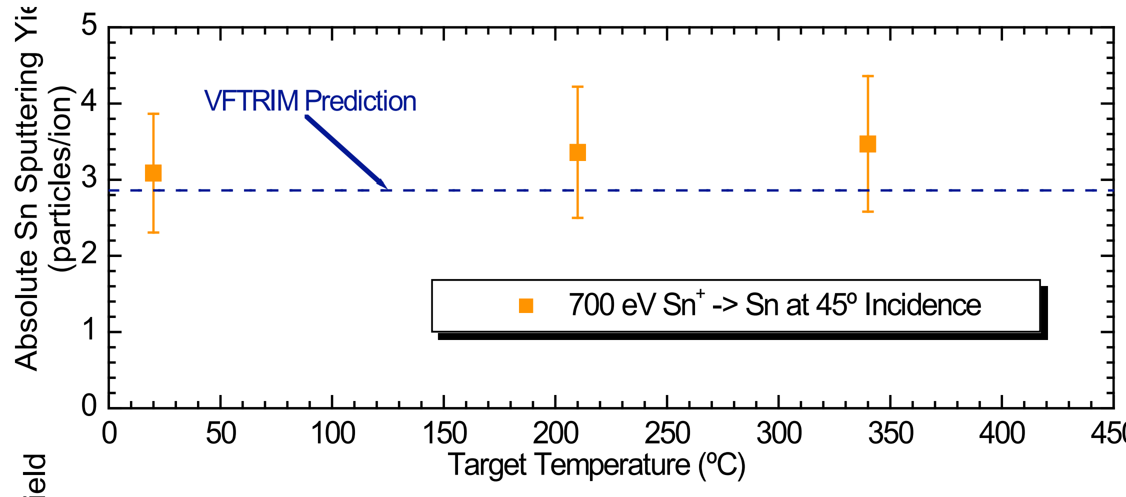
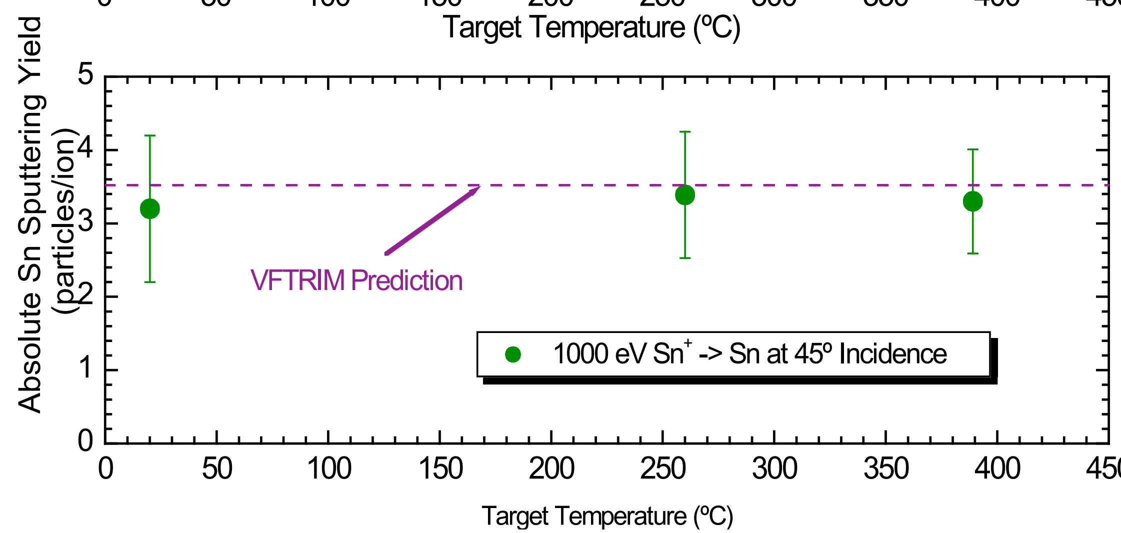
Sn self-sputtering measurements

- Early data indicate that Sn self-sputtering is also not significantly enhanced by temperature at least up to 400ºC
- These results are similar to those for both Ne^+ and Ar^+ sputtering of Sn (from a temperature enhancement perspective)
- Important to note that higher temperatures may still yet show temperature-enhanced properties





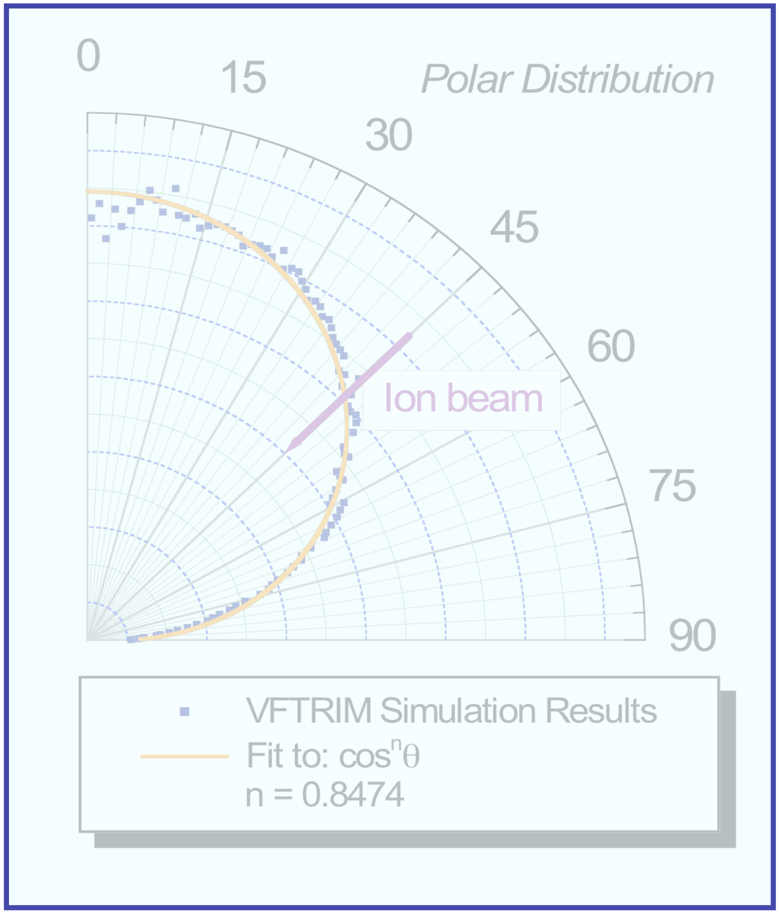
Recent improvements

- Data analysis
  - Using VFTRIM “data” of sputtered particle angular distributions to help calculate how much of the ejected material intersects our monitoring crystal
- Hardware upgrades
  - Ion beam system
    - Neutral filter
    - Vertical steering near target
  - Target and QCM system
    - High temperature ability

Improved estimate of "geometric factor": 1

In general…

- This "geometric factor" is just an integral over the QCO crystal surface that estimates what fraction of the sputtered material strikes (but not necessarily sticks to) the crystal
- VFTRIM simulations are now performed for each ion-target combination to generate sputtered particle distribution "data" to input into the computation of this geometric factor



1000 eV $Sn^+ \rightarrow Sn$ at 45º incidence

(Polar angle)

- *A* and *n* are fit such that $A \cdot \cos^n\theta$ fits the VFTRIM polar "data"
- Previously assumed $\cos^1\theta$ polar distribution – This correction of *n* made little difference in the final result

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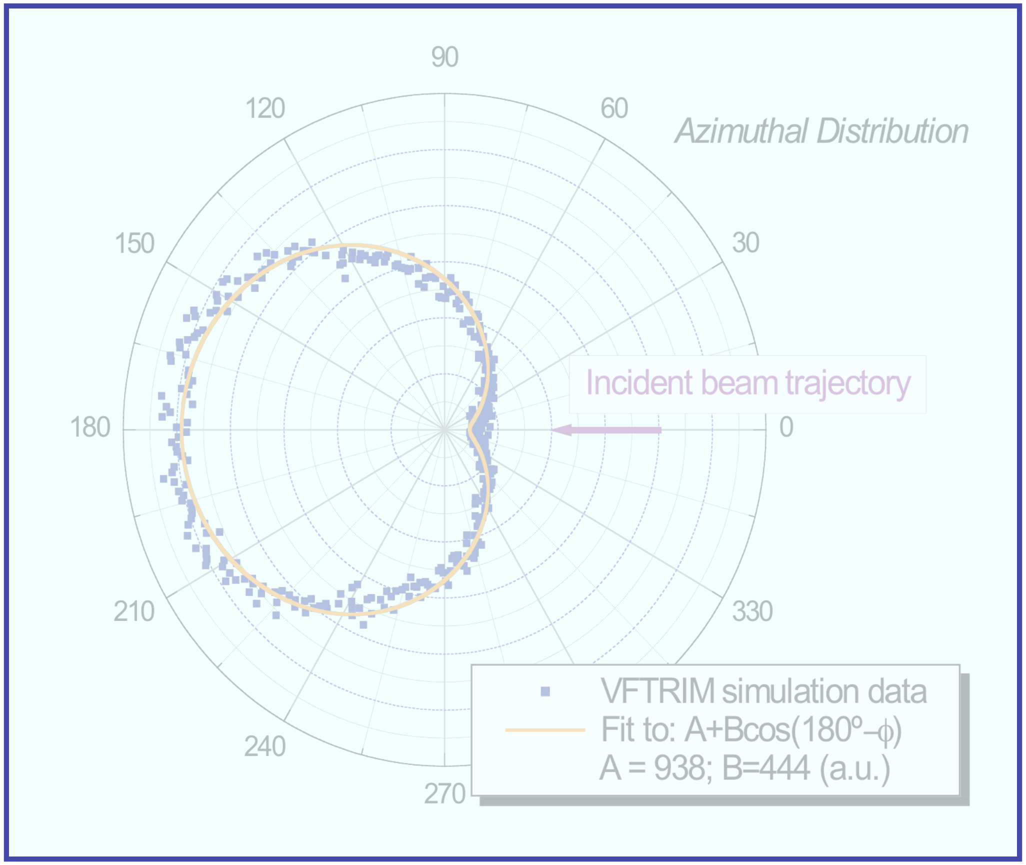
Improved estimate of "geometric factor": 2



1000 eV $Sn^+ \rightarrow Sn$
at 45º incidence

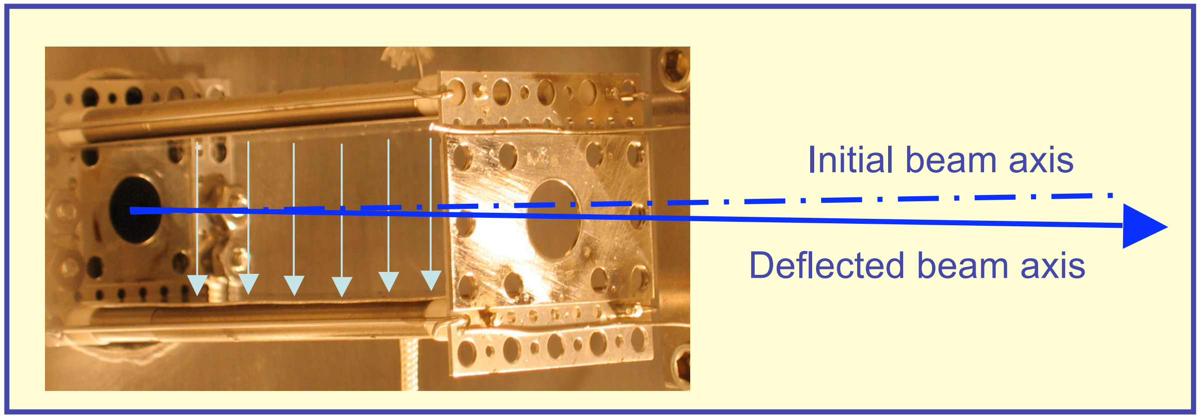
(Azimuthal angle)

- Previously assumed azimuthal isotropy
- Significant anisotropy due to oblique incidence
- Parameters *A* and *B* are varied using *$A + B \cdot cos(\varphi - \pi)$* to fit VFTRIM azimuthal distribution "data"

(NOTE: This function is just a guess that fits most data sets well and so doesn't necessarily have a physical interpretation)

Ion beam system modification
Neutral filter installation

- Installed horizontal deflection plates to make 3º bend to filter neutrals
  - Previously relied on Wien filter E-field to bend beam followed by 10 – 15 cm of 3.5-cm diameter tubing (along unbent beam axis)
  - Now, horizontal deflection for neutral filtering is performed after entering the main chamber to minimize neutral component
  - Unfortunately, this has degraded beam performance (as expected)



Prior target temperature was limited

- Two factors…
  - Poor thermal considerations in target/heater holder design limited target to ~550ºC
  - Above ~420ºC, the QCM units would fail due to being close to the hot target without active cooling

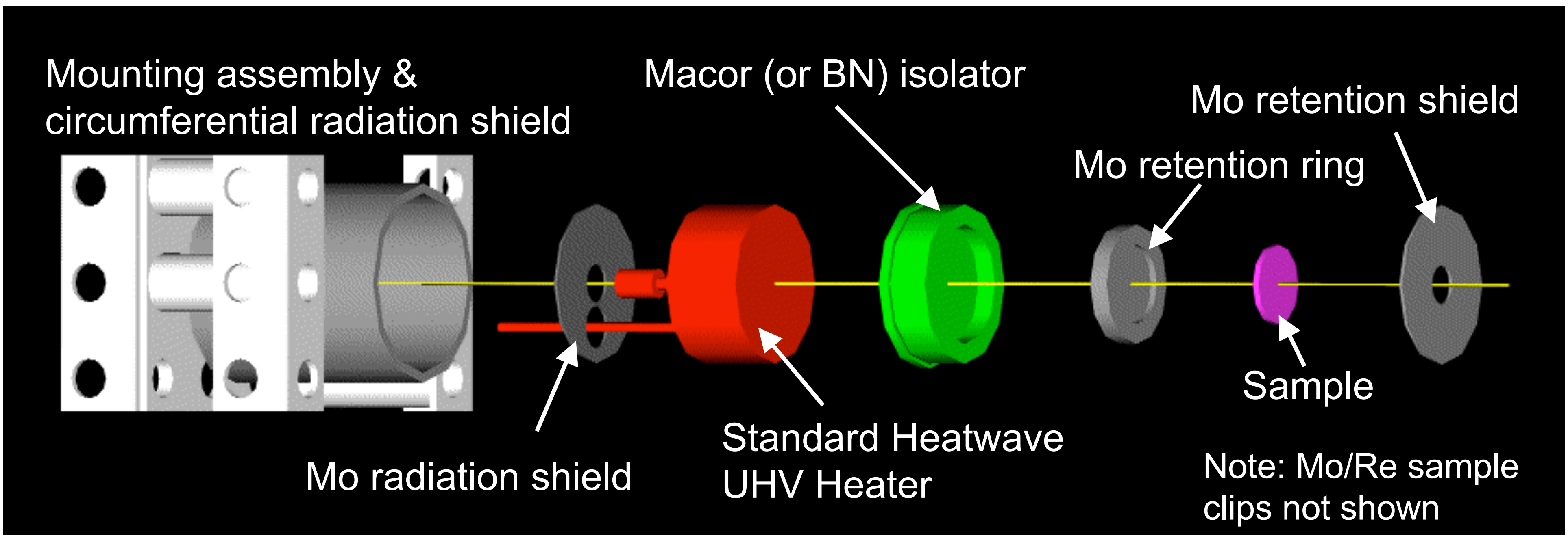
- Recent hardware upgrades to allow high temperature measurement
  - Repaired QCM head for electrically-isolated water cooling
  - Installation of new target holder
  - Goal: Reach 1000ºC (Heater rated for 1200ºC)

Modification to QCM head:
Electrically-isolated water cooling

- Benefits:
  - Greatly improved crystal stability (better signal to noise ratio) at all temperatures
  - Able to exceed 870ºC without crystal failure with no apparent limit as of yet (heater power limit should be ~1100ºC)
  - Maintaining the same crystal temperature for all target temperatures
  - Use of a ceramic break and deionized water maintains electrical isolation
- Drawbacks:
  - Greatly reduced mobility of QCM head due to stiff “flexible” water lines
  - Marginally degraded base pressure due to use of Swagelok fittings (low 8’s versus mid 9’s on a good day)

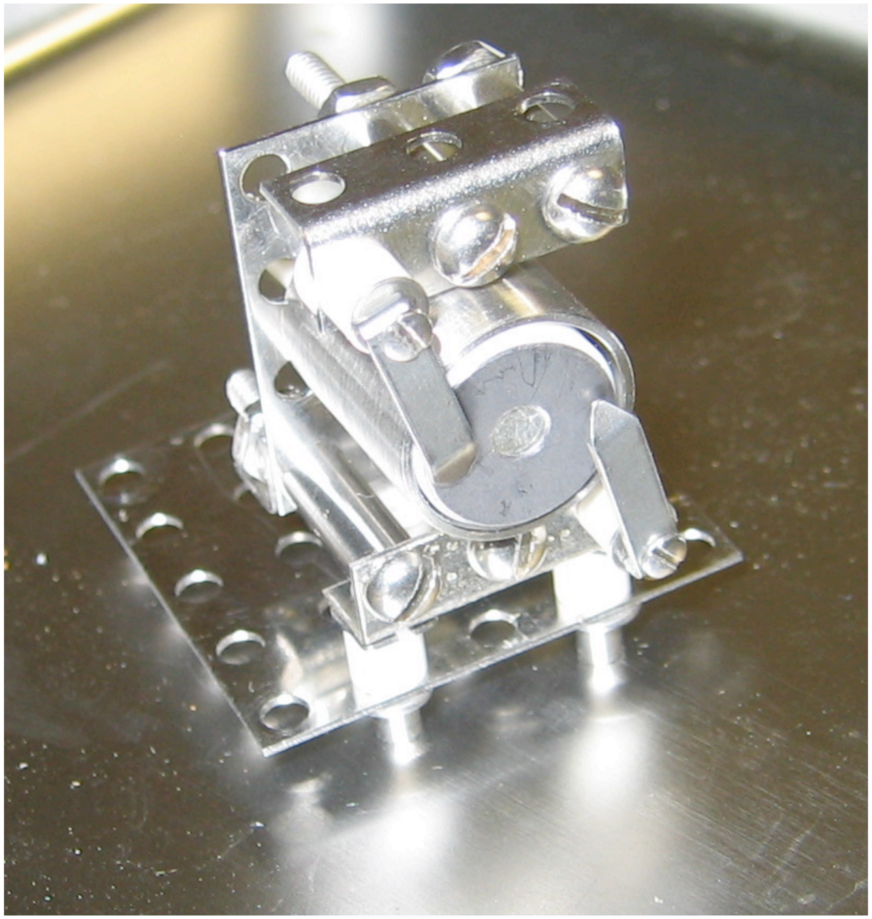
Heater & liquid sample holder redesign

- Thermal considerations
  - Minimized thermal contact between heater/target components and mounting hardware
  - Radiation shield around circumference (SS) and behind (Mo) heater to minimize radiative losses

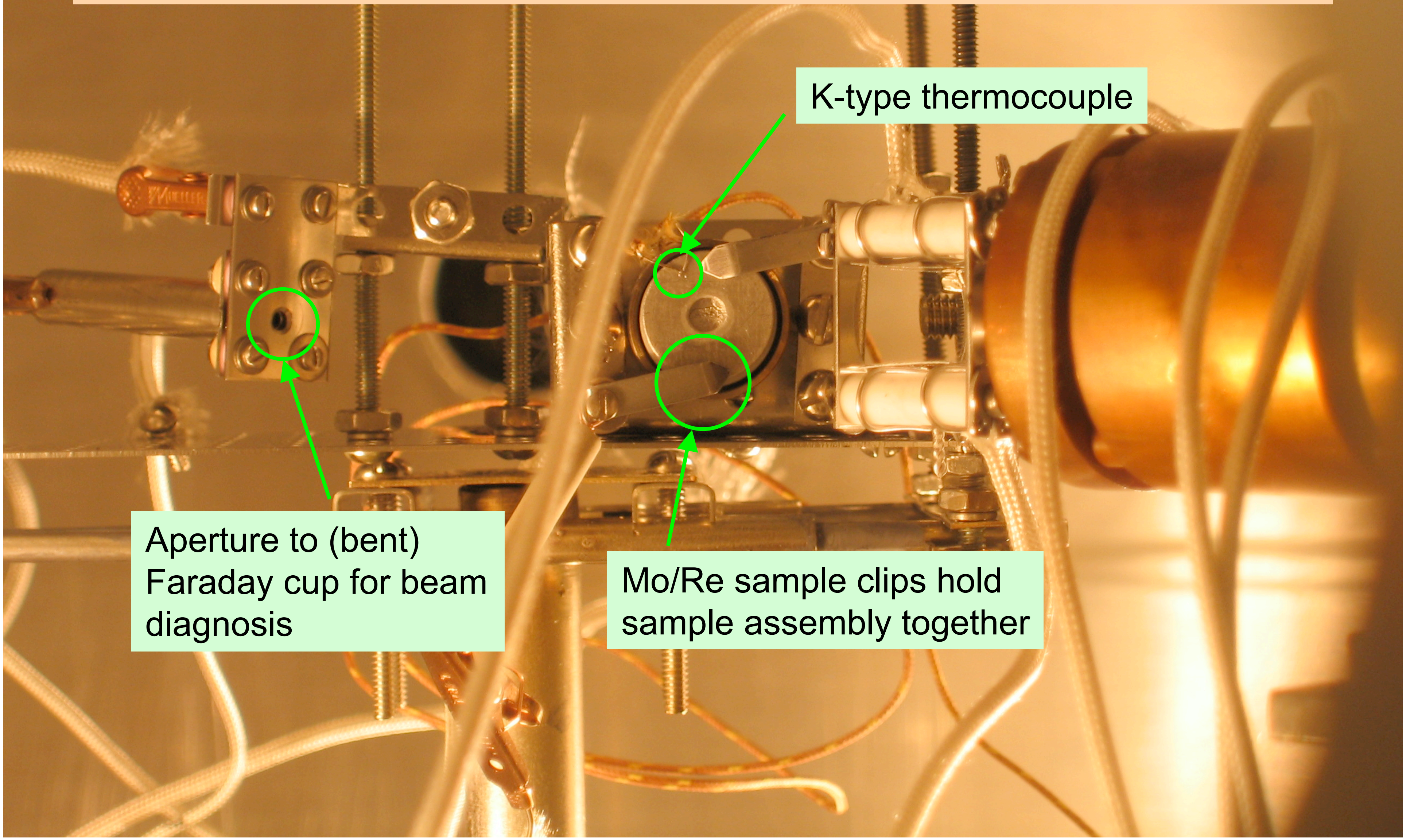


New sample holder construction

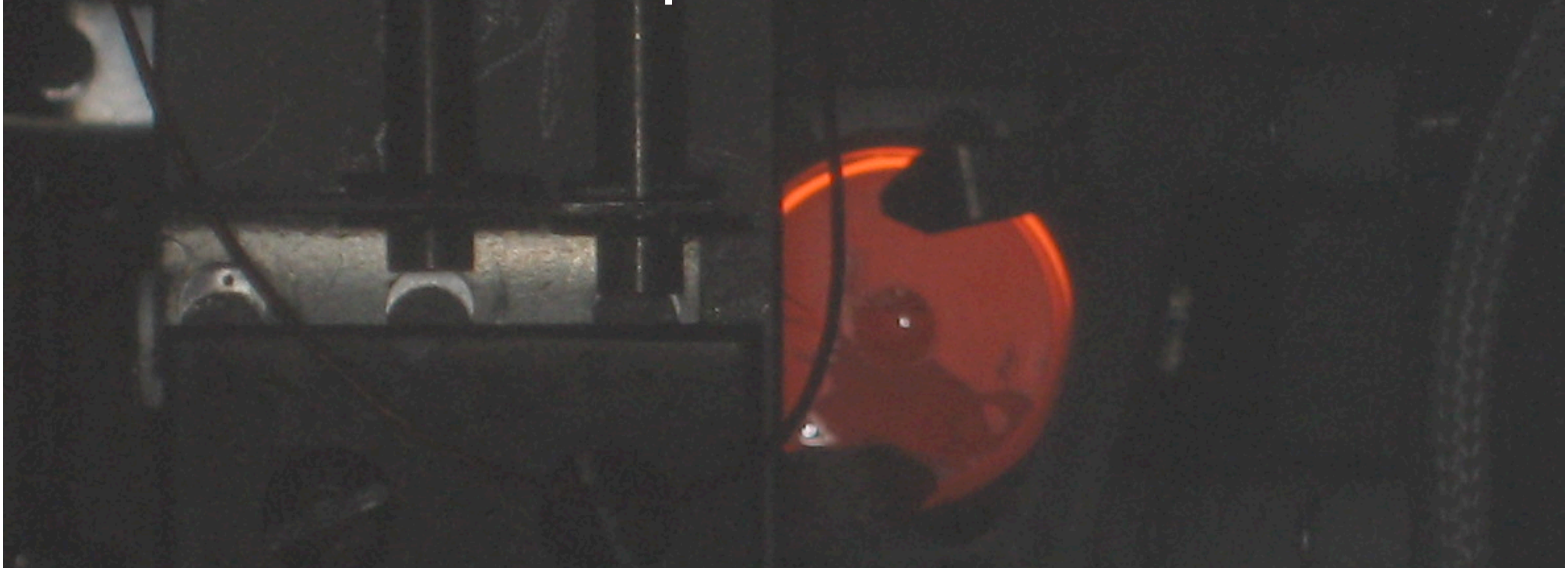
- Currently, only one assembly ‘hard’ mounted
- Goal: Several interchangeable sample assemblies
- Quick assembly replacement (through 6” CF port)
- Two samples mounted with others ready to minimize down-time
- Need:
  – Design & construction time
  – Feedthough
  – UHV-grade plugs



New sample holder in place



New sample holder in use



- Presently, we're limited by the heater power circuit to ~870ºC but reaching 1100ºC is achievable assuming T^4 scaling (has shown to be pessimistic so far)
- Some of this sample spilled out, but was otherwise well-behaved and showed a beautifully-reflective surface

Summary of modifications

- With improved data analysis techniques and an improved ion beam system, our data quality is improved
- To date, hardware limitations have kept our sample temperatures at or below 400ºC; since a Sn divertor's evaporation-limited temperature limit is estimated to be 1200ºC[1], higher temperature (and lower energy) measurements are needed
- IIAX hardware upgrade should allow sample temperature of at least 1100ºC

[1] Brooks, J.N., *Modeling of sputtering erosion/redeposition – status and implications for fusion design.* Fus. Eng. Des., **60** (2002) p515-526.

Future Work

- Near-term:
  - *Focus on light ion (He^+ & D^+) sputtering of liquid Sn at higher temperatures – up to 1000ºC*
  - *Return to heavy ion sputtering (Ne^+, Ar^+, and/or Sn^+)*
  - *Reduce ion energies used (ideally to 100-200 eV with use of decelerator)*
- Longer term:
  - *Temp. dep sputtering of liquid Sn & Ga*
  - *Model apparent mass-dependence of temperature-enhanced sputtering*
  - *Li^+ or Sn^+ sputtering of Mo & LM-coated Mo*
  - *Measurement of the ionized fraction of sputtered material of PFC*
  - *Mixed **solid** material sputtering relevant to ITER (W, Be, C, etc.)*

Acknowledgements

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